MAC ecohydrology

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Ecohydrology By Thinking Outside The Bog

Shifting paradigms in an era of shifting peatland ecosystems

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12th British Hydrological Society National Symposium - Penman Lecture 03Sep2014

Northern Peatland Ecosystems

Ecosystem Services

Important ecosystem services:
~33% of global carbon pool
~10% of global surface fresh water

Northern Peatland Ecosystems

Long-term carbon sink

Peat accumulates because of cool and (very) wet soil conditions
Plant production exceeds decomposition (and combustion)

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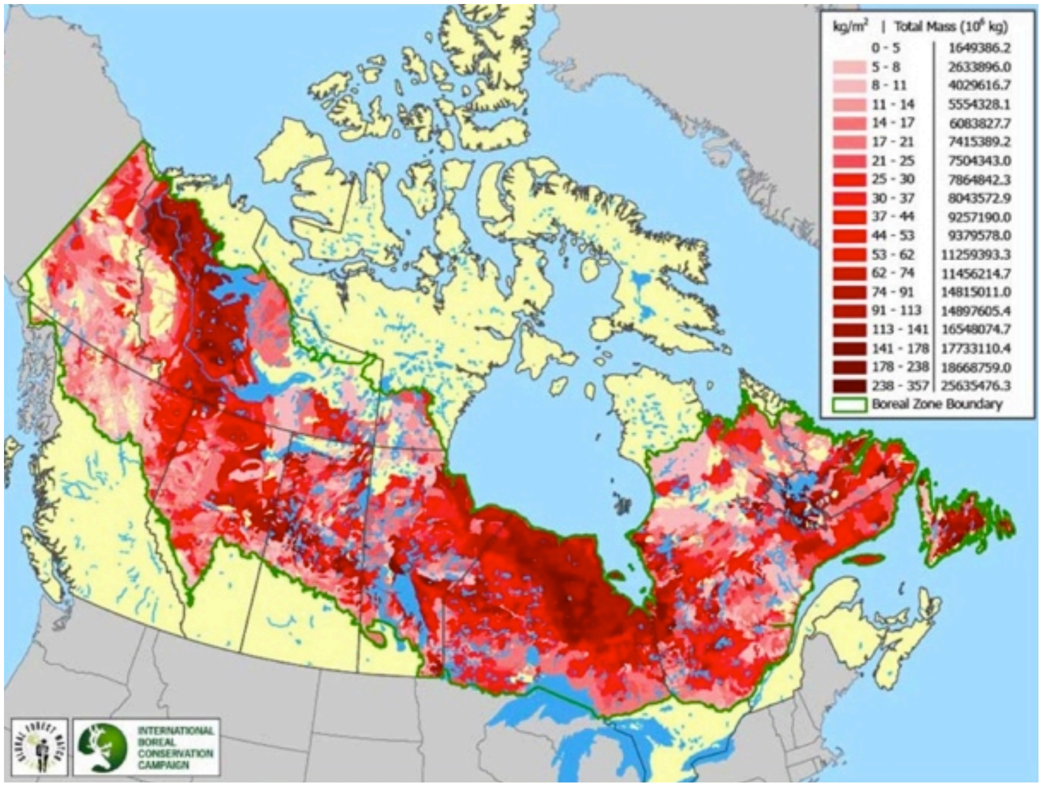
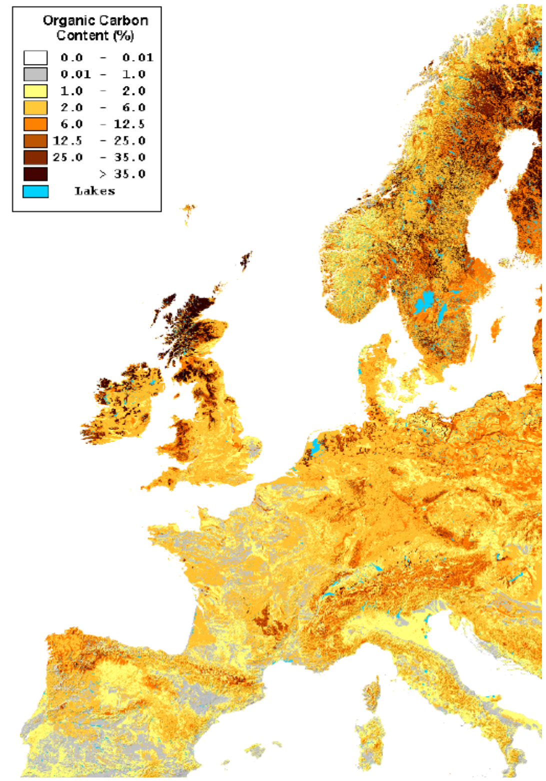
Source: Silkeborg Museum (Silkeborg, Denmark)

Northern Peatland Carbon Storage

Canada and United Kingdom





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Source: International Boreal Conservation Campaign

Northern peatland 'National Wealth'

Gross Domestic Peat (GDP)

Country	Area (10^6 km^2)	Peat Area (km^2)	Peatland Coverage (%)	Population (millions) 2013	Peat Area per (m^2) per capita
Canada	9.97	1.13×10^6	12	35	32285
Finland	0.34	85000	25	5.4	15741
Russia	17.8	1.41×10^6	8	143	9860
Sweden	0.41	66000	16	9.6	6875
USA	9.63	0.63×10^6	6	314	2006
UK	0.24	17500	7	63	278

Global peatland coverage: ~4.5×10^6 km^2

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Source: Modified from Tim Moore (McGill University, Montreal, Canada) CERC presentation. January, 2014.

Gross Domestic Peat

Canada and United Kingdom

185 Gt	3120 Mt

*assuming current carbon value of £5/t

£925 billion	£15.6 billion
(£25,000/person)	(£250/person)

Chisholm Fen (Central Alberta, Canada)

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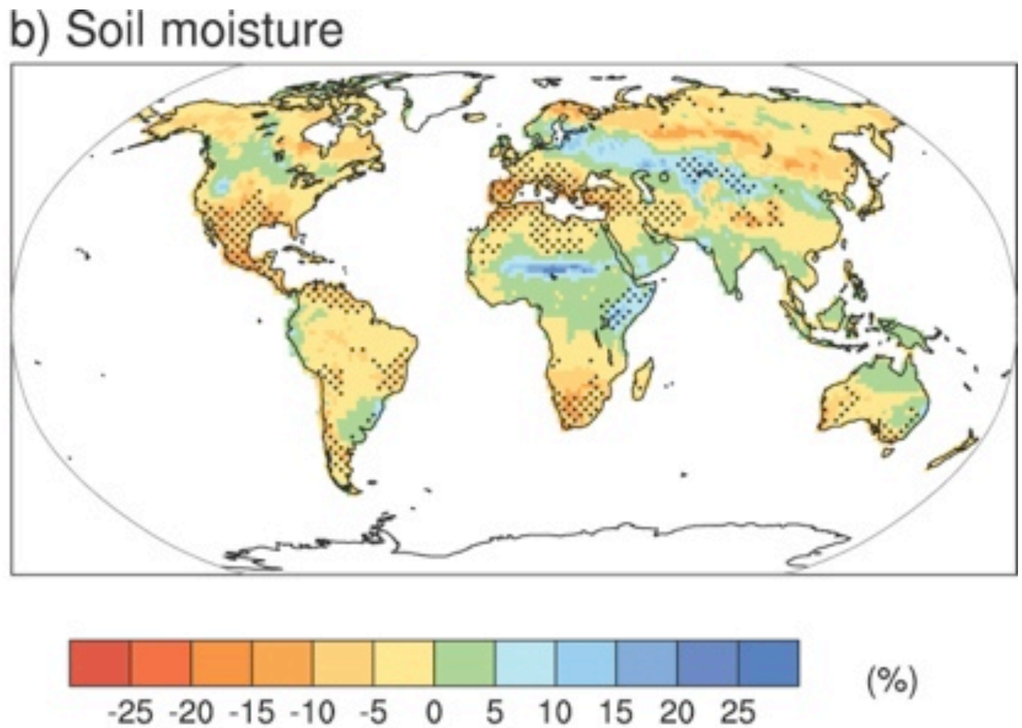
Northern Peatland Ecosystems

Vulnerable or Resilient to Ecosystem Disturbance?

Land-use disturbance

Climate-mediated disturbance



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Source: IPCC, 1997

INVITED COMMENTARY

HP TODAY

HYDROLOGICAL PROCESSES
Hydrol. Process. **18**, 3439–3445 (2004)
Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/hyp.5761

Ecohydrology and hydroecology: A 'new paradigm'?

Hannah DM, Wood PJ, Sadler JP. 2004. Hydrological Processes

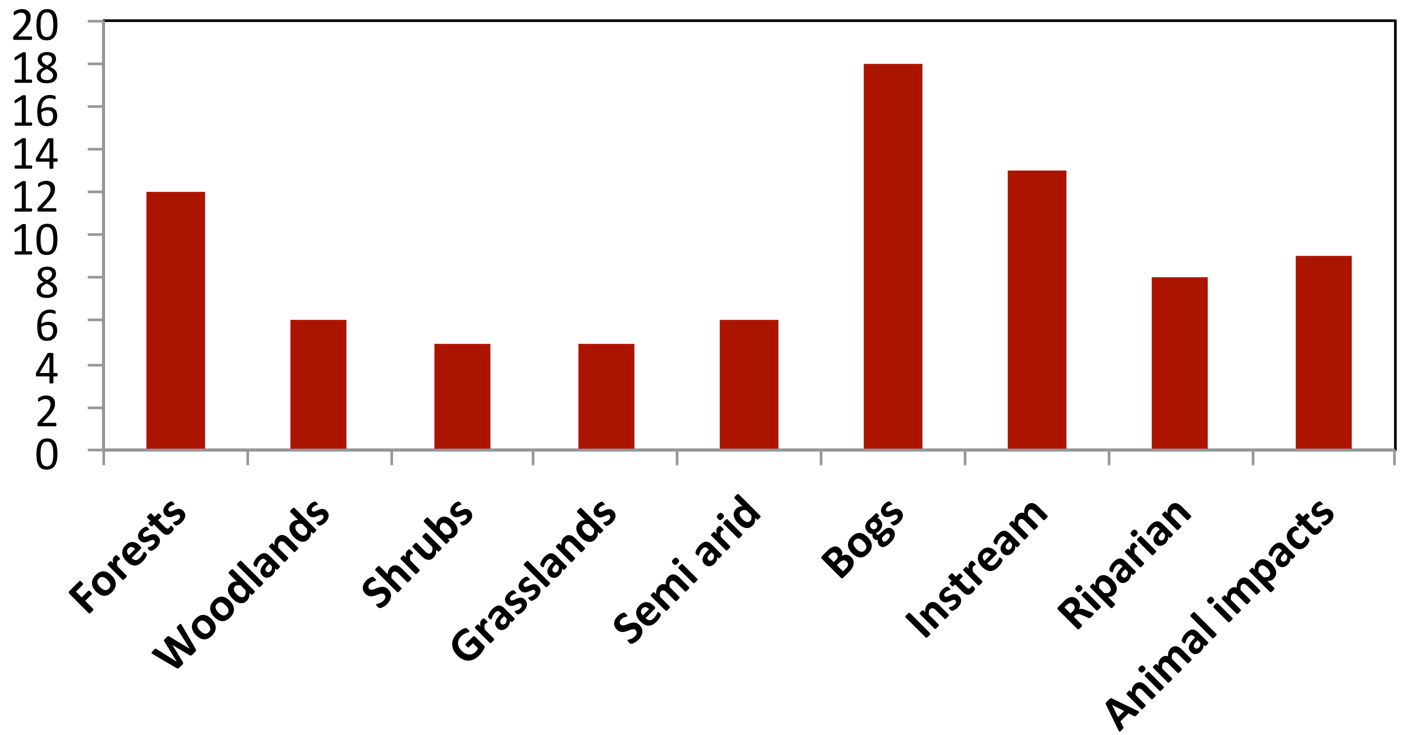
"If a true paradigm shift is to occur:

- "ecologists and hydrologists need to bridge the gap between traditional subject(s)…. to build real interdisciplinary teams
- "benefit from the synergies of working at the cutting edge of research in both hydrology and ecology.

Northern Peatland Science

A long established ecohydrological discipline?

Papers (%) published in Ecohydrology by ecosystem

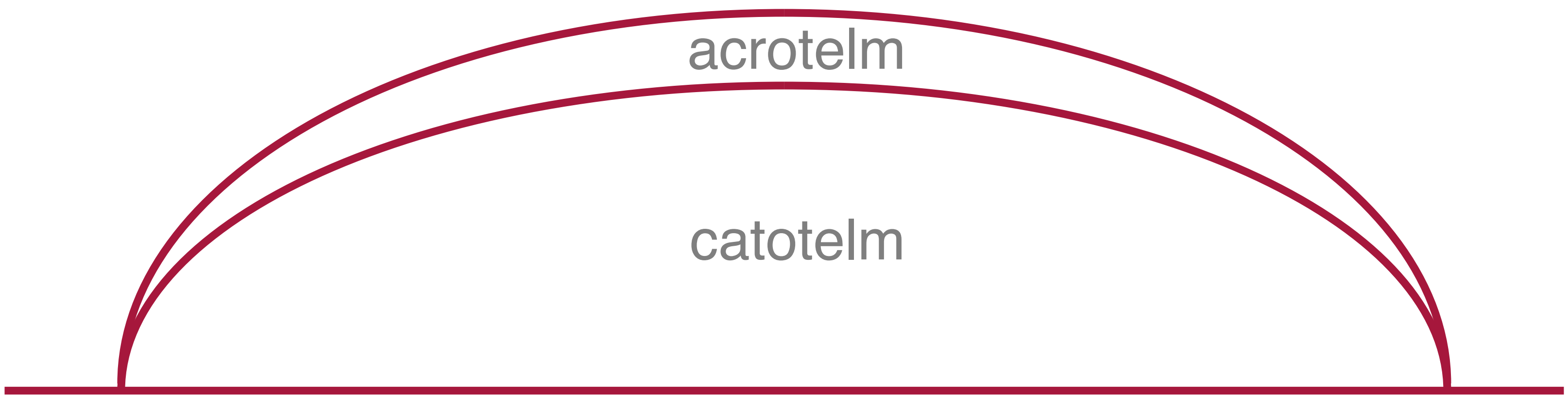


Northern Peatland Science

The acrotelm-catotelm peatland bog paradigm

- Simple models of peatland development (Ingram,1978)
- Two soil layers: acrotelm (high K_{sat}) and catotelm (low K_{sat})
- Depth to drought water table hypothesized to control decay

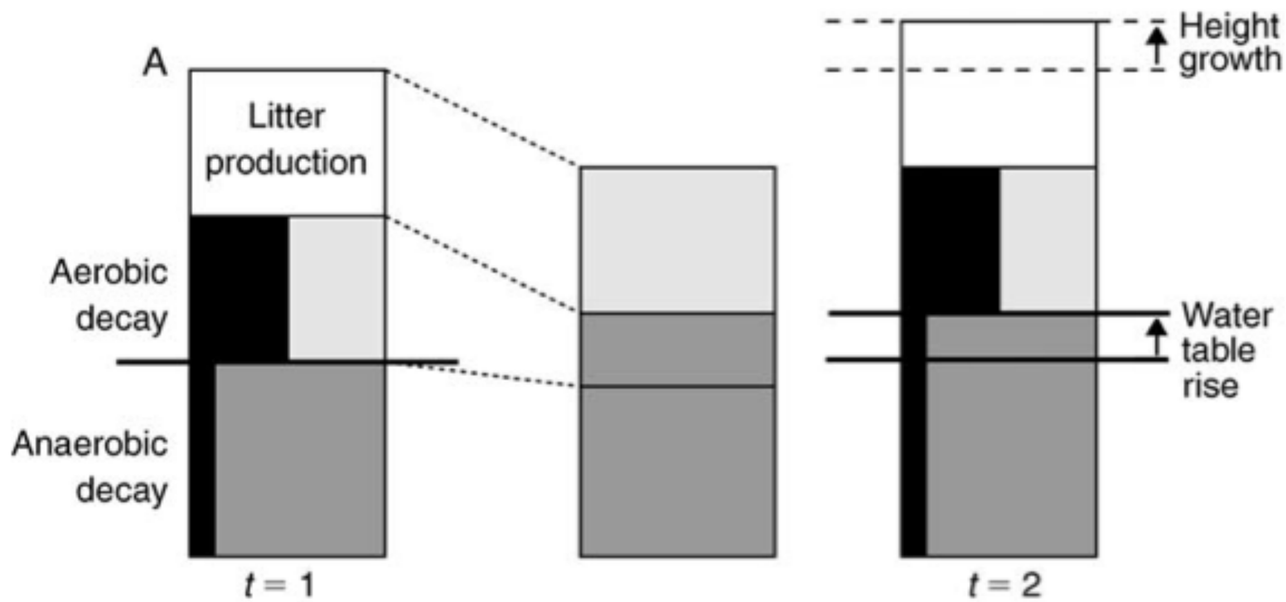
regime, peat quality, pore structure, etc



Northern Peatland Ecosystems

The acrotelm-catotelm peatland bog paradigm

- Limits to peat bog growth (Clymo, 1984)
- Coupled hydrology, ecology and carbon biogeochemistry



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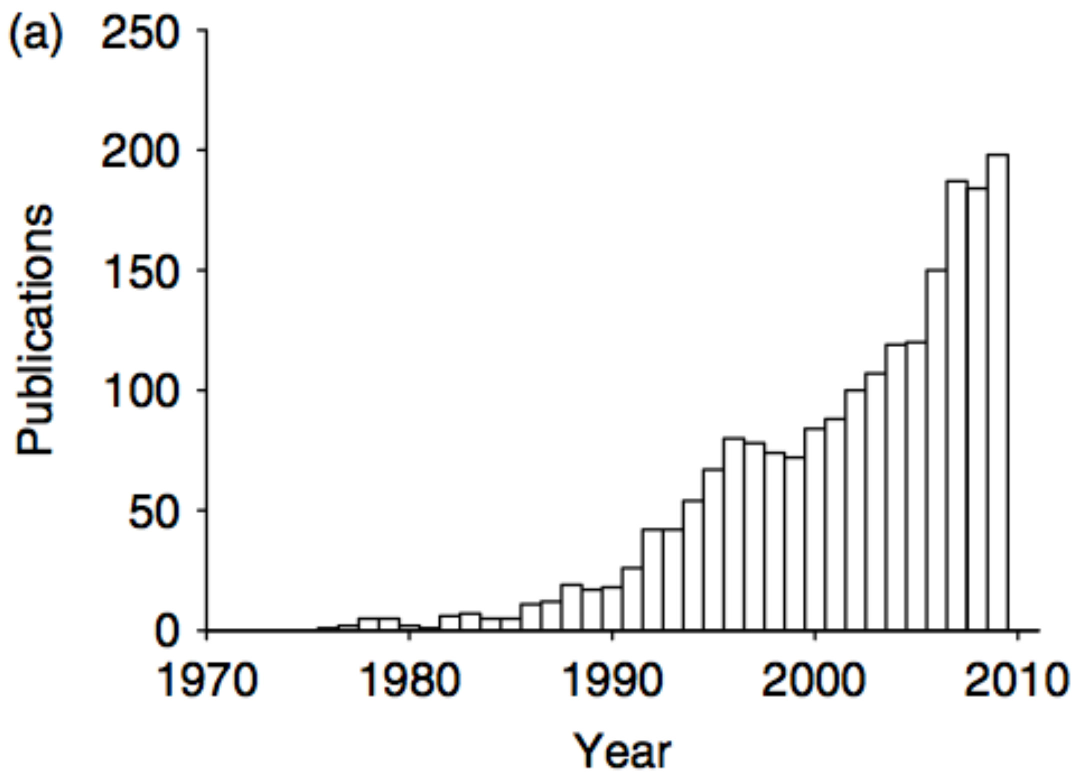
Source: Belyea and Baird (2006) Ecological Monographs

Conceptual frameworks in peatland ecohydrology: looking beyond the two-layered (acrotelm–catotelm) model†

Paul J. Morris,[1]* J. Michael Waddington,[1] Brian W. Benscoter[2] and Merritt R. Turetsky[3]



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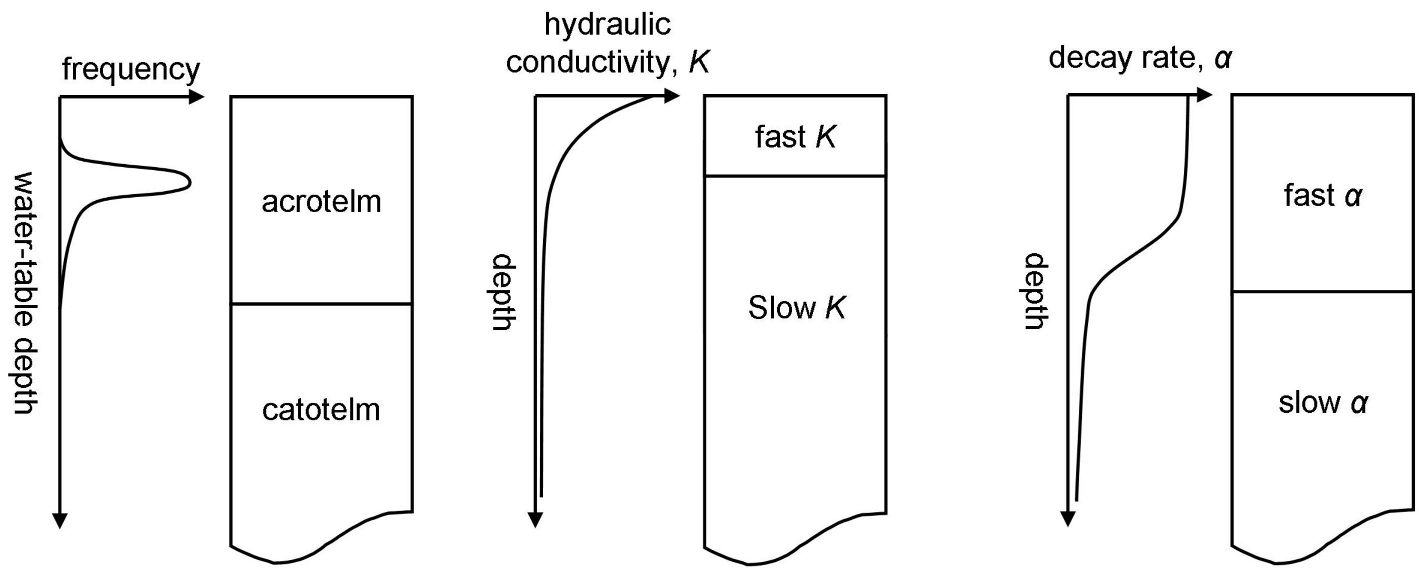
Source: Morris et al (2011) Ecohydrology

Northern Peatland Ecosystems

Challenging the acrotelm-catotelm peatland paradigm

- Does not consider spatial heterogeneity
- Same boundary layers for all processes
- Inflexible for a changing layer thickness (mining, fire, deformation)



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Source: Morris et al. (2011) Ecohydrology


frequency
water-table depth
acrotelm
catotelm
?
Riviere-du-Loup Bog (Riviere-du-Loup, Quebec)
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frequency
water-table depth
acrotelm
catotelm
?
Siikaioki Fen (Siikaioki commune, Finland)
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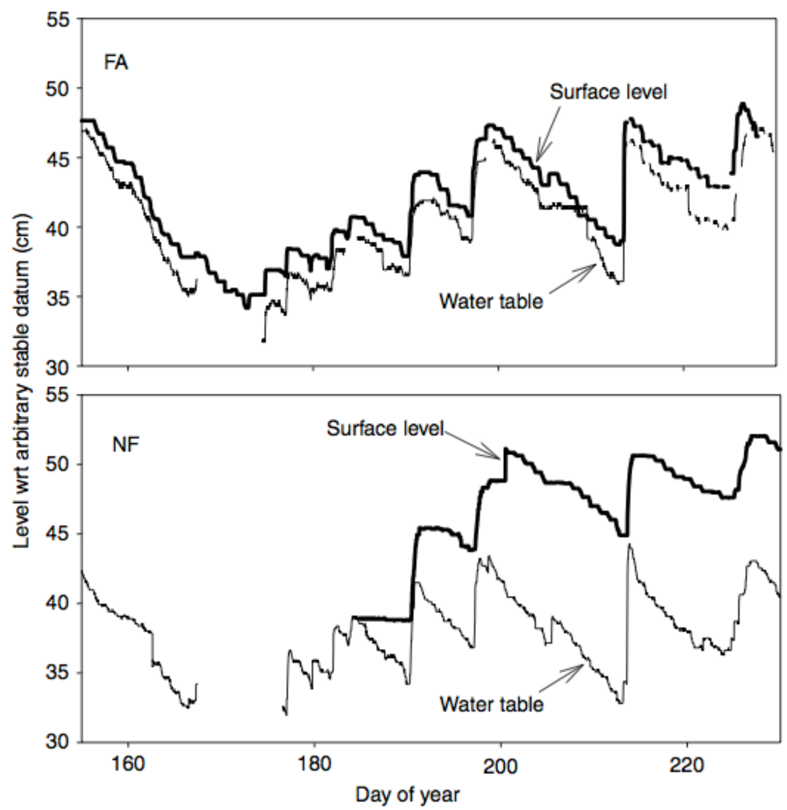
Northern Peatland Ecosystems

The acrotelm-catotelm peatland bog paradigm

Peat deformation causes the surface to float and/or subside



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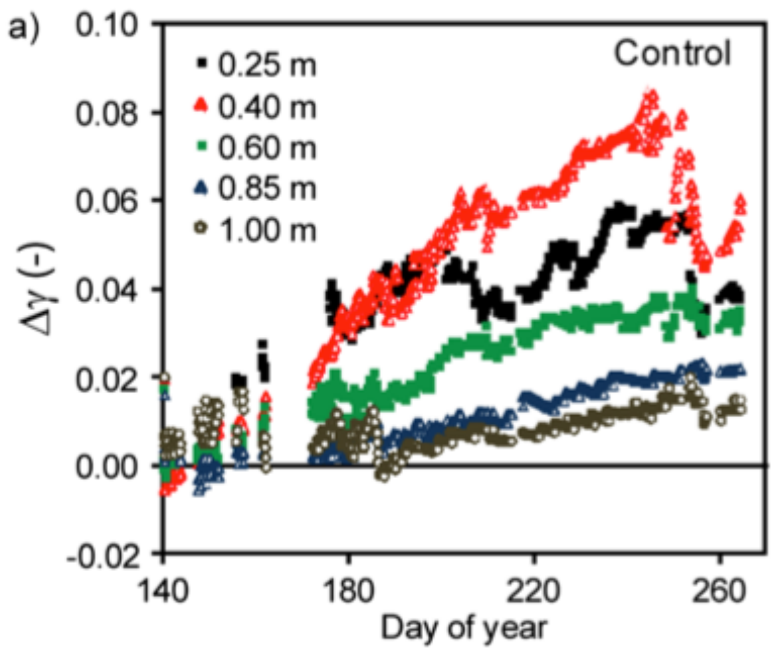
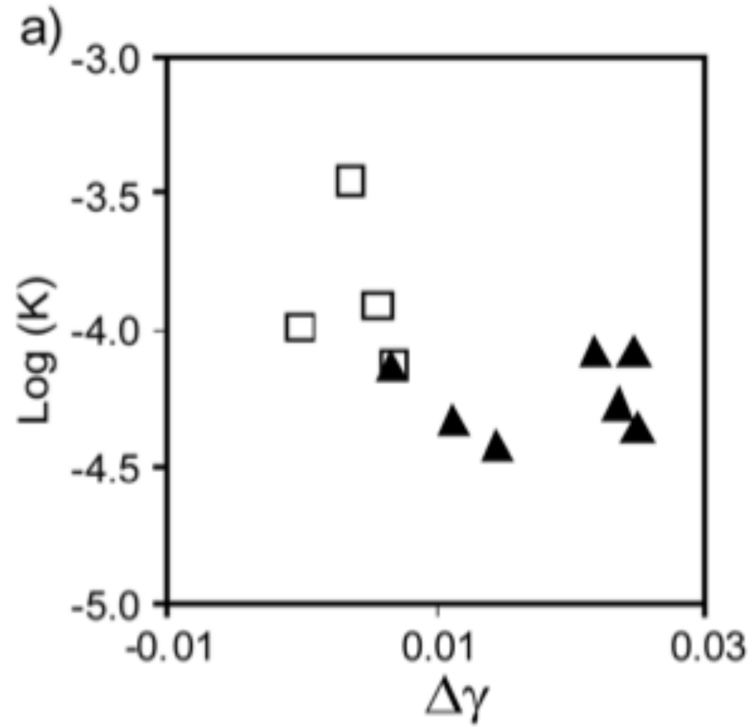
Source: Stack, Kellner and Waddington (2006) Hydrological Processes

Northern Peatland Ecosystems

The acrotelm-catotelm peatland bog paradigm

Entrapped gas bubbles can reduce K_{sat} an order of magnitude





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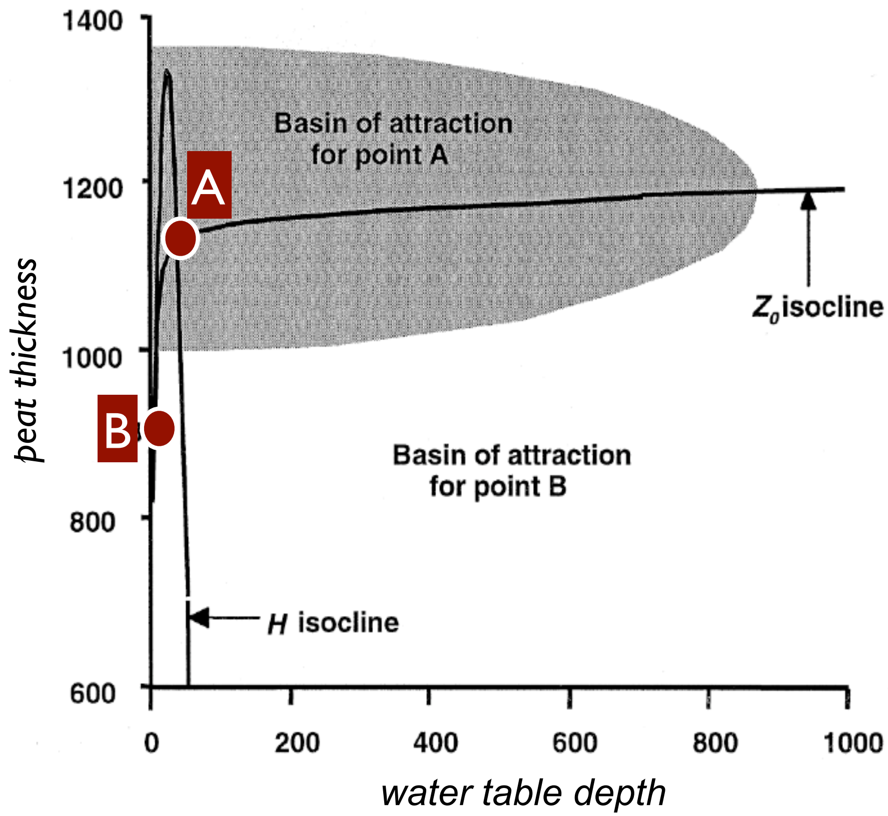
Source: Kettridge et al (2014) Hydrological Processes

New Paradigm – Resilience Theory

Process hydrology and quantify ecohydrological thresholds



Regime shift may be invoked by:

Decrease water table

OR

Decreasing peat surface

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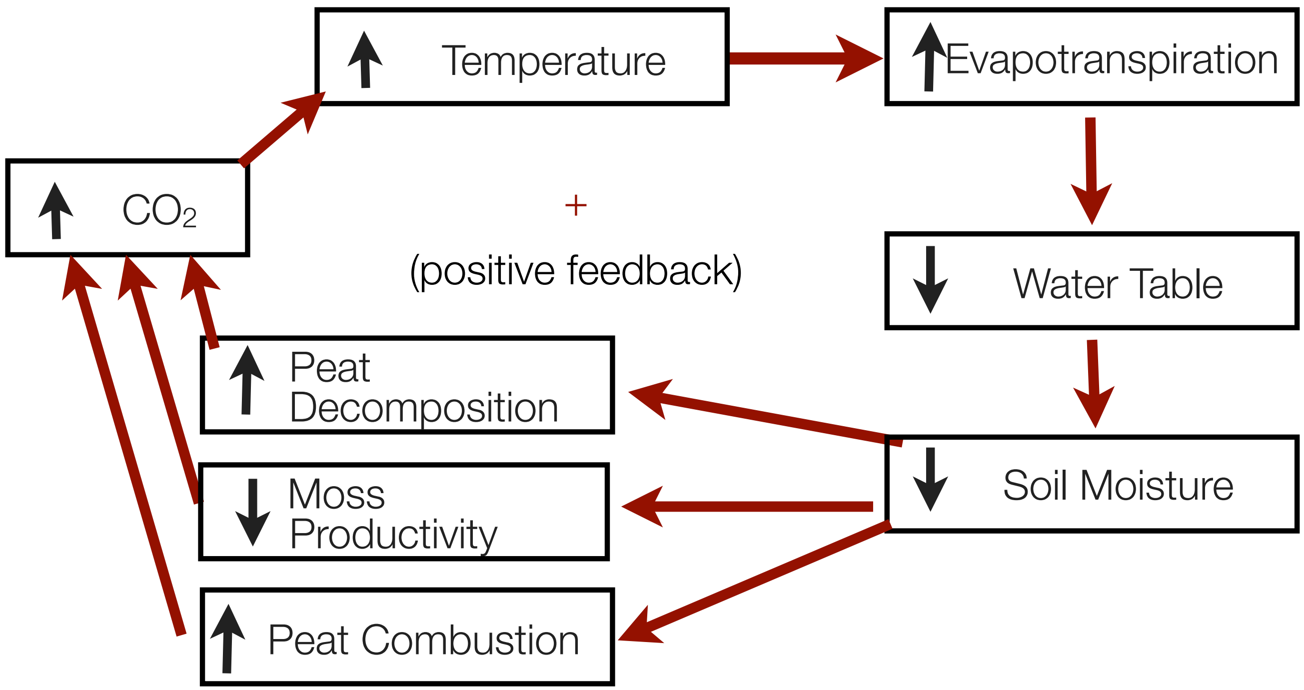
Source: Hilbert et al., (2000) Journal of Ecology

Shifting Peatland Ecosystems?

Vulnerable to climate change?

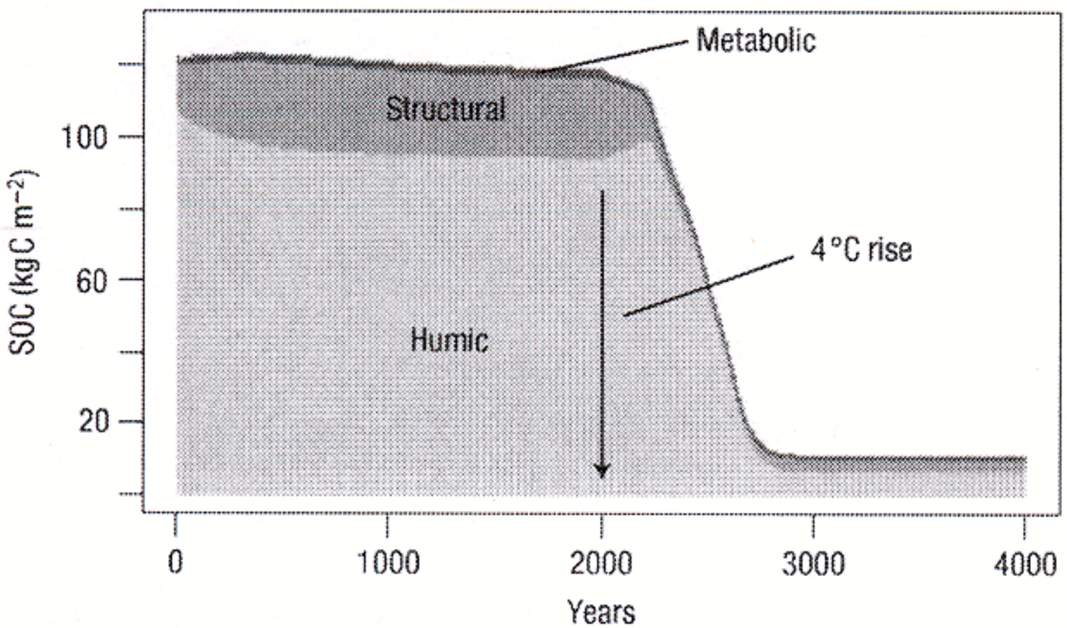
Hydrological, ecological and soil carbon biogeochemistry response hypothesized to amplify the climate system



Northern Peatland Ecosystems

Vulnerable to climate change?

'Coupled' hydrology and ecology modelling predicts northern peatlands will lose > 125 g C m^{-2} for centuries



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Source: Ise et al. (2008) Nature Geoscience

Evidence of peatland ecosystem shifts

Water table drawdown experiments

We have designed numerous water table drawdown experiments in search of field evidence of ecosystem shifts and large carbon losses




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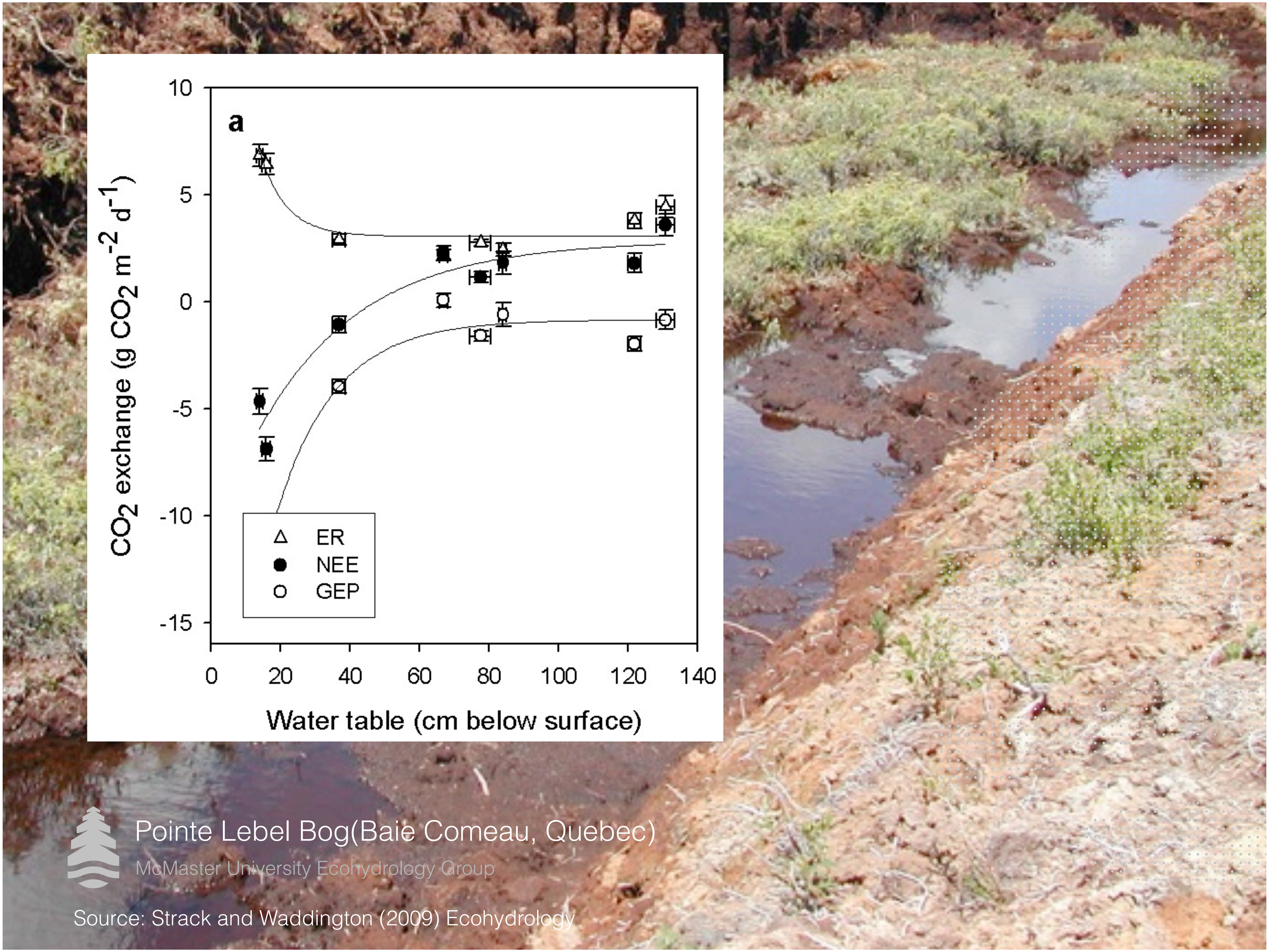

Pointe Lebel Bog(Baie Comeau, Quebec)

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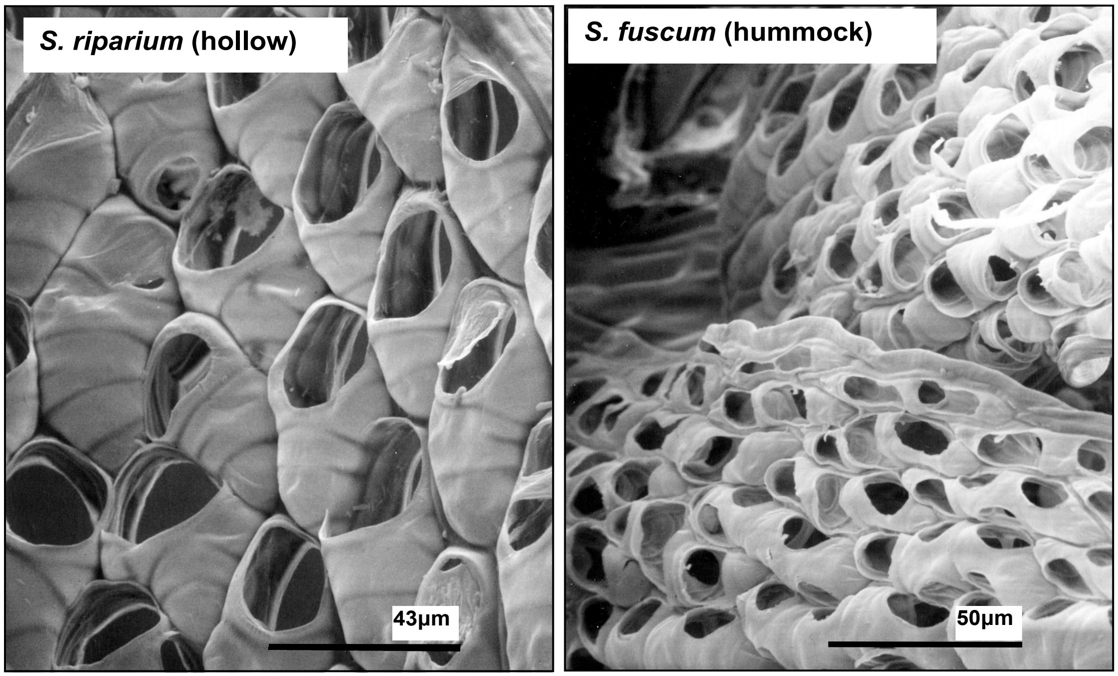
Source: Strack and Waddington (2009) Ecohydrology

Moss Species matter

Decomposition and moisture retention



Hummock species have better moisture retention (and lower decomposition) than hollows.

Dynamic moss enhances resilience to disturbance.

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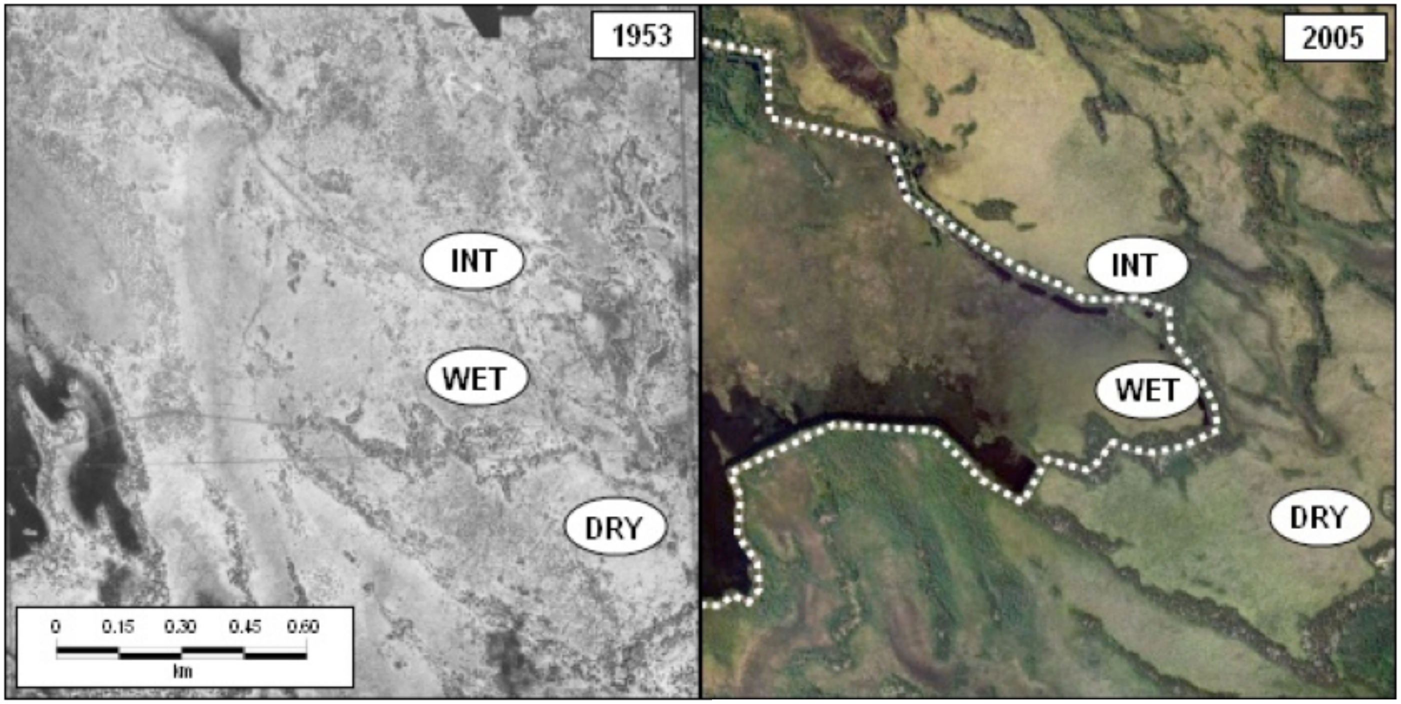
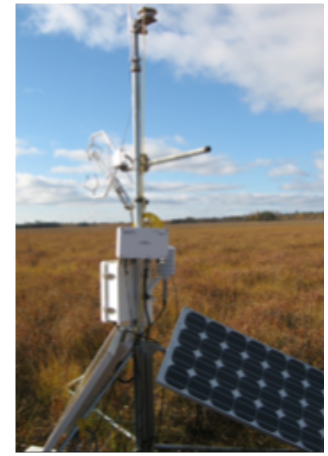
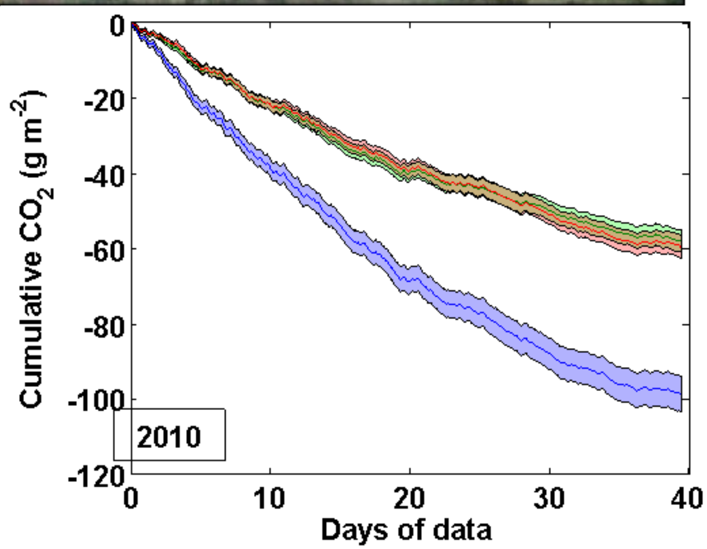
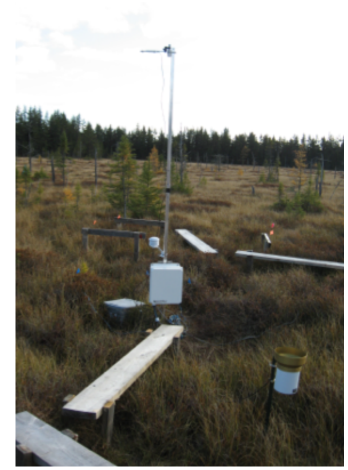
Source: Turetsky et al. (2008) Journal of Ecology









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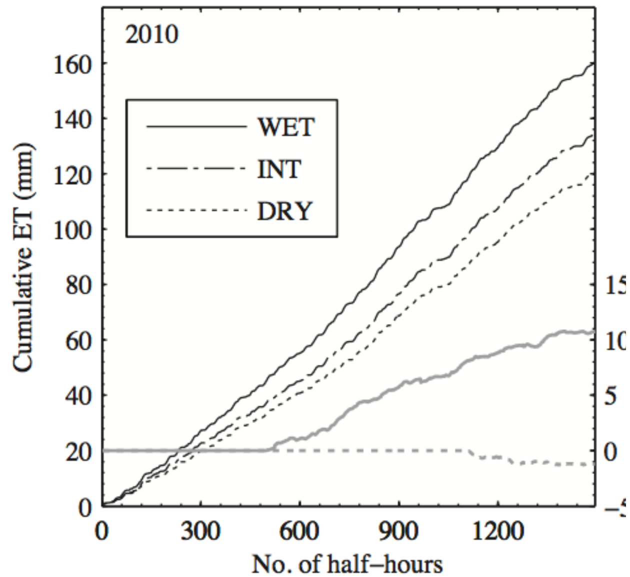
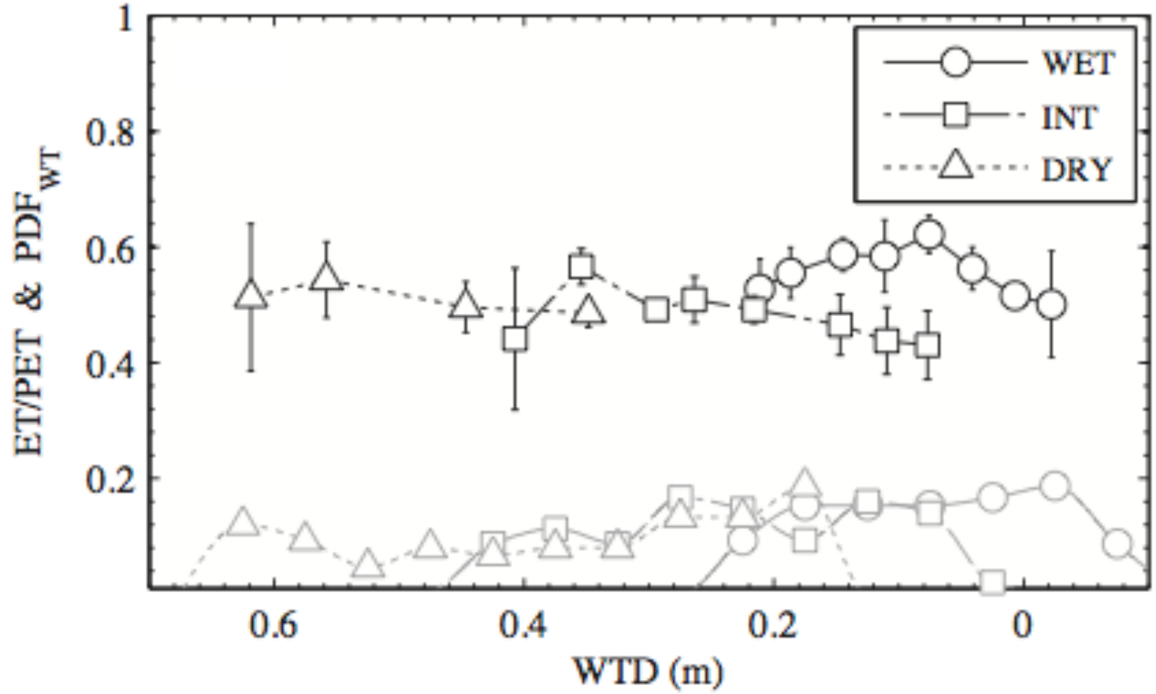
Source: Moore, Pypker, and Waddington (2013) Agricultural and Forest Meteorology





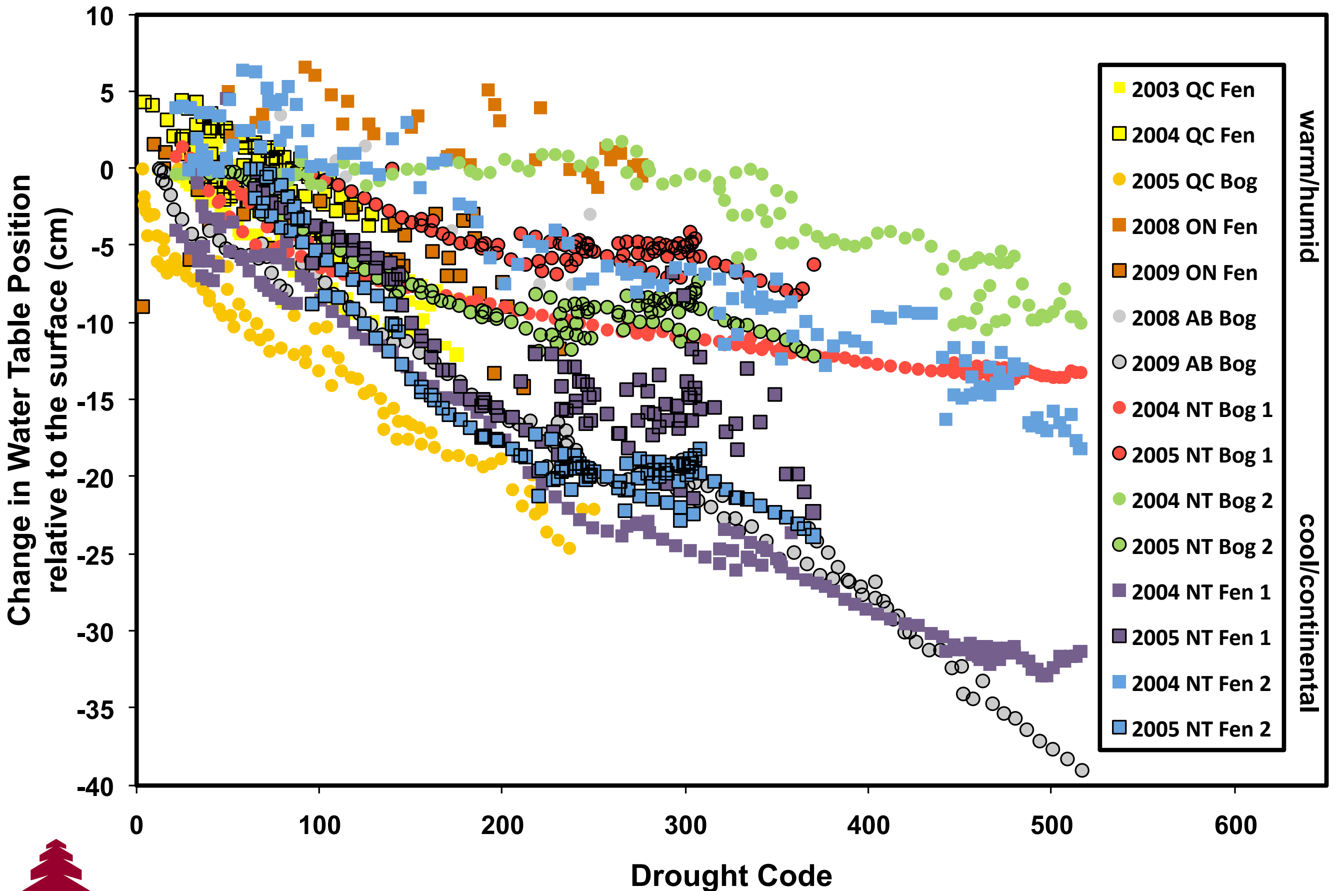
Wet > Int > Dry

But no change in ET/PET due to the impact of long-term change in WTD on leaf area and the relative distribution of plant functional groups.

Source: Moore, Pypker, and Waddington (2013) Agricultural and Forest Meteorology

Peatland Ecohydrology

Negative feedbacks dominate



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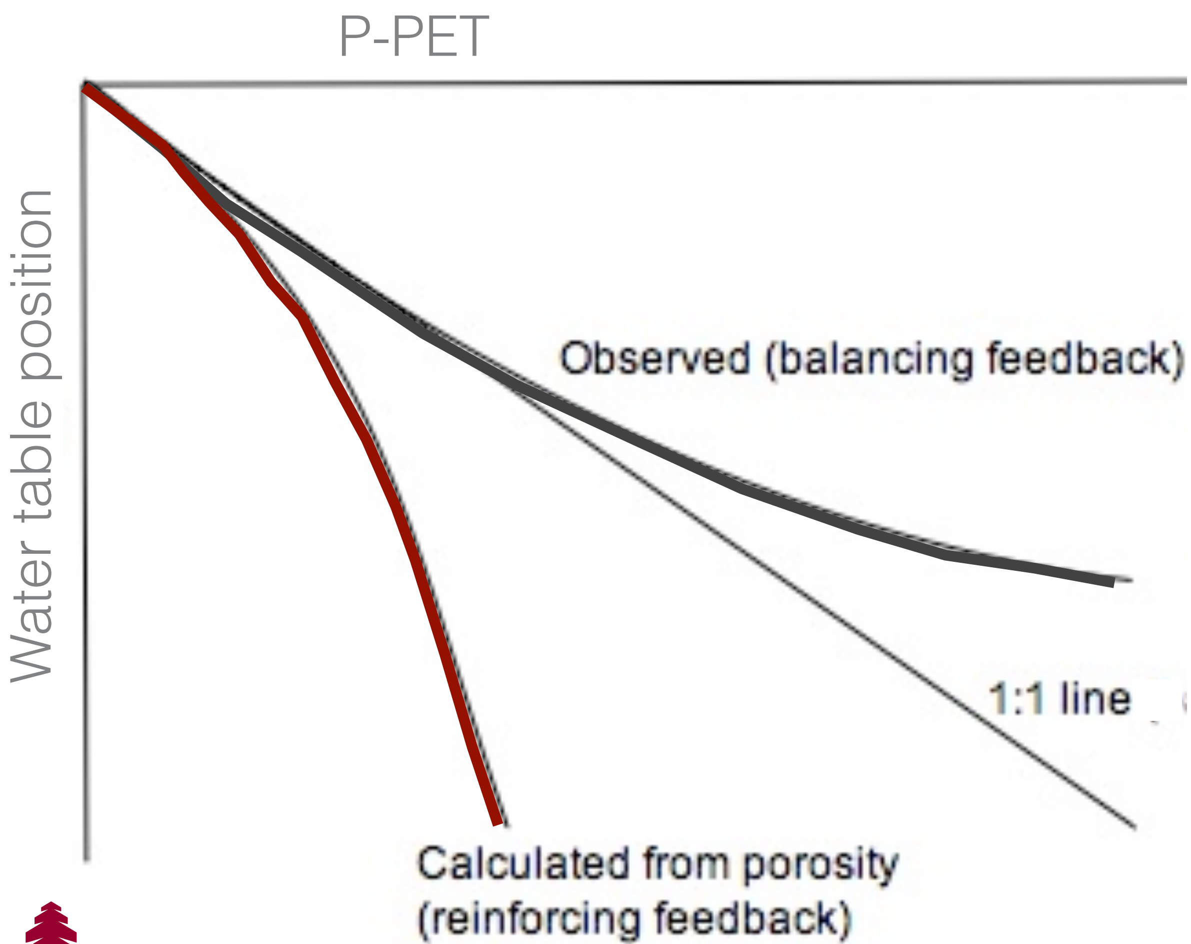
Source: Waddington et al., (2012) Canadian Journal of Forest Research

Peatland Ecohydrology

Negative feedbacks dominate



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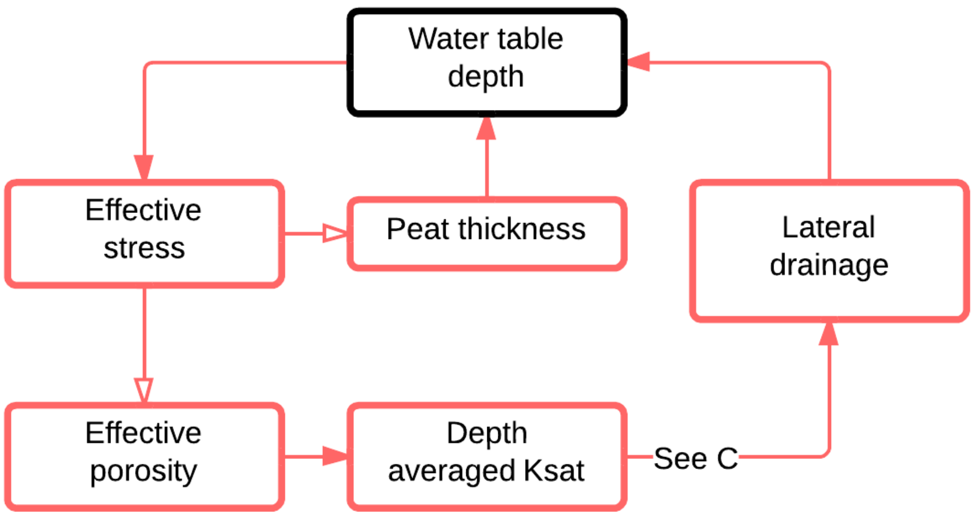
Source: Waddington et al., (2012) Canadian Journal of Forest Research

Northern Peatland Ecosystems

Ecohydrological Feedbacks

Peatland ecohydrology is controlled by strongly coupled feedbacks among vegetation type, litter production and quality, decomposition, hydraulic properties, and hydrodynamics.



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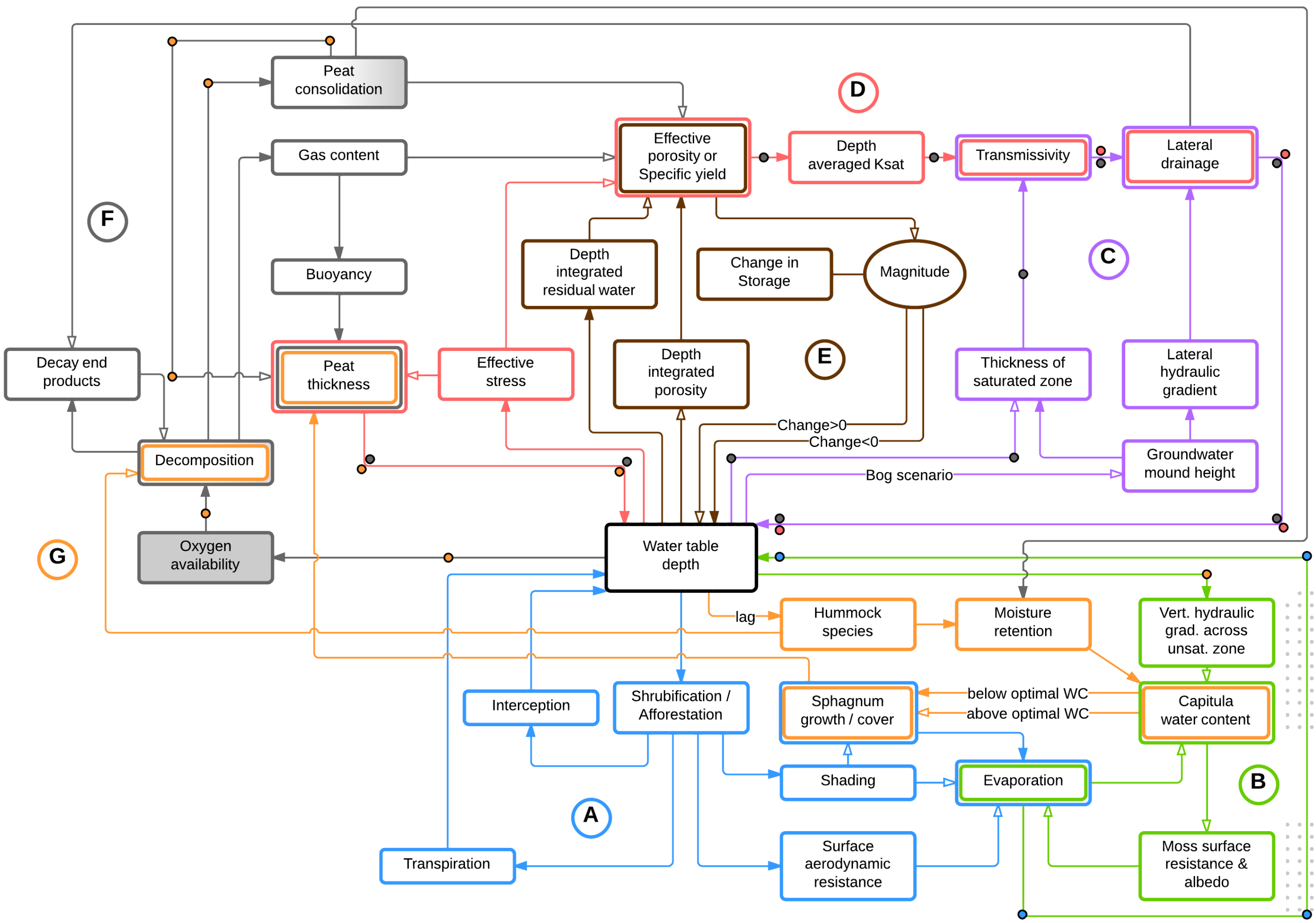
Source: Waddington et al (2014) Ecohydrology

Ecohydrological Feedbacks



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Source: Waddington et al. (2014) Ecohydrology

Peatland Ecohydrology and Resilience

Negative feedbacks dominate

	*Maritime Climate Peatlands** ** excludes blanket bogs*		*Continental Climate Peatlands*	
	Bog / Poor Fen	**Rich Fen**	**Bog / Poor Fen**	**Rich Fen**
A) WTD – afforestation and/or shrubification feedback	**	*	+++	+
A_1 *transpiration and interception*	++	+	+++	+
A_2 *shading and evaporation*	--	0	+++	+
A_3 *aerodynamics*	++	0	+++	+
B) WTD – moss surface resistance and albedo feedback	-	0	---	0
C) WTD – transmissivity feedback	--	---	0	-
D) WTD – specific yield feedback *(falling WT, see text)*	++	+	+++	+
E) WTD – peat deformation feedback	--	---	0	-
F) WTD – peat decomposition feedback	---	--	--	--
F_1 *water residence time – porewater chemistry*	---	--	--	--
F_2 *water residence time – entrapped gas*	--	--	--	--
G) WTD – moss productivity feedback	---	-	*	0
G_1 *moss species moisture retention*	---	0	---	0
G_2 *decomposition – peat moisture retention*	--	---	0	-

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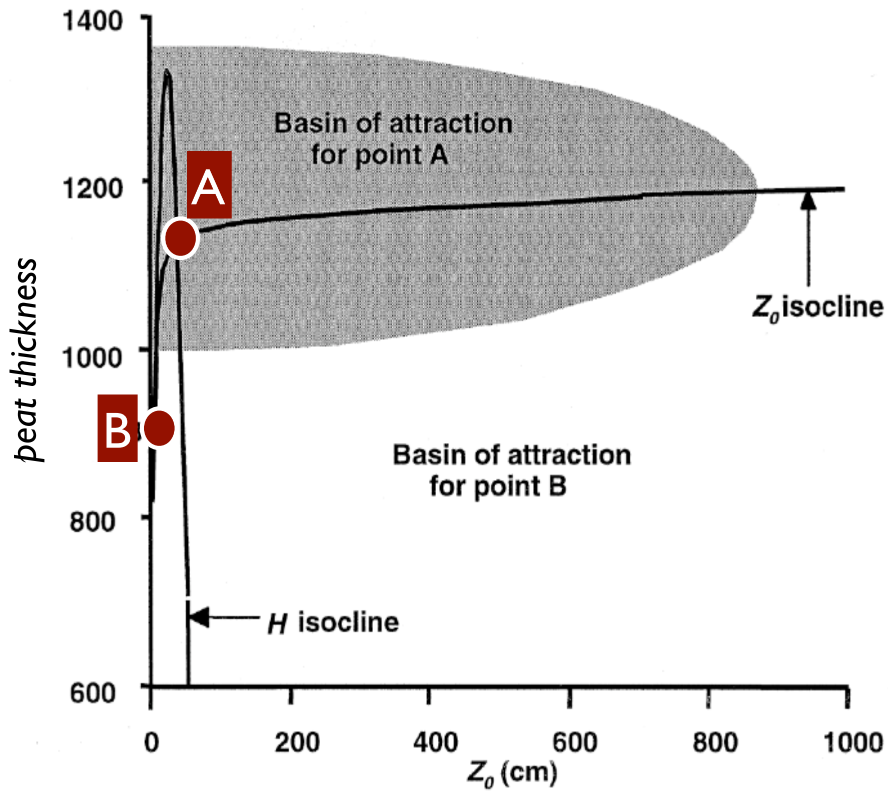
Source: Waddington et al. (2014) Ecohydrology

Are Peatland Ecosystems Shifting?

Theory and field evidence suggests peatlands are resilient



State shift invoked by:

Decrease water table
(drainage, drought)

AND

Decreasing peat surface
(wildfire, mining)

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Source: Hilbert et al., (2000) Journal of Ecology

Peatland Regime Shift

Drained and mined peatland

Pointe-Paradis Peatland (Baie Comeau, Quebec)

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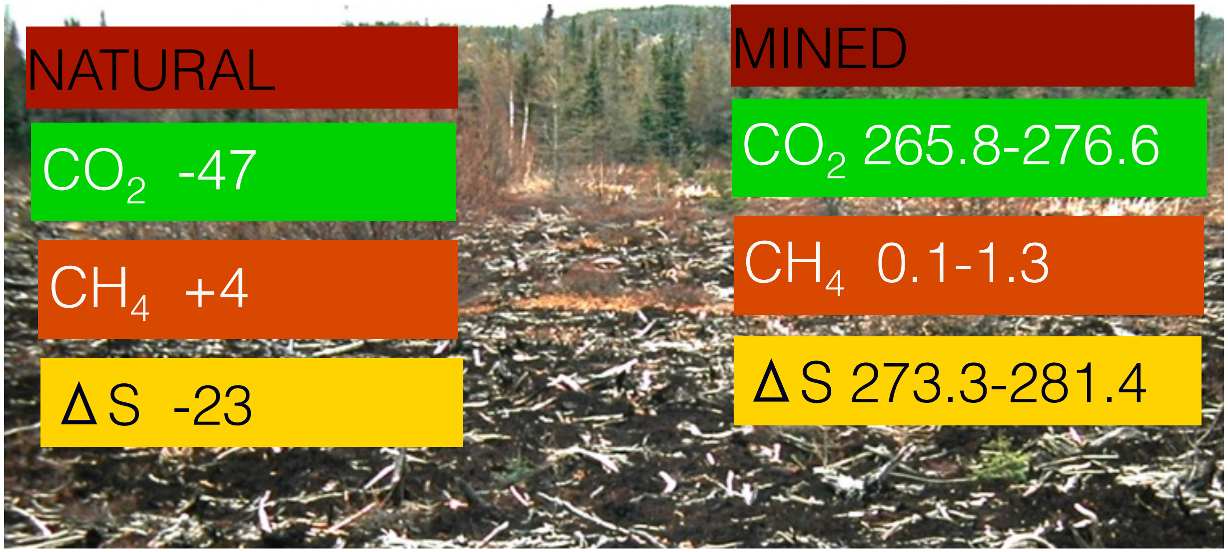
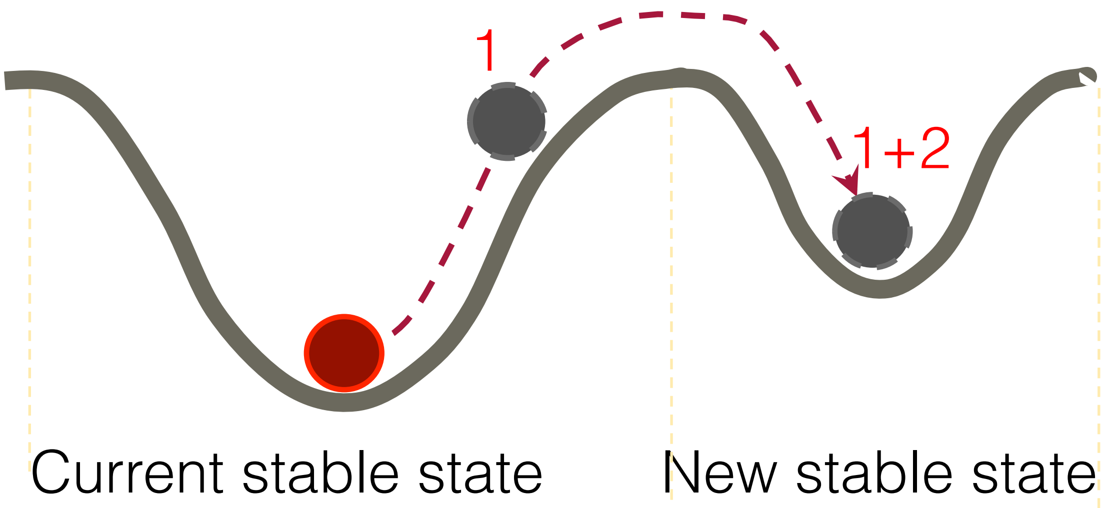
Peatland Regime Shift

Large and persistent source of atmospheric carbon



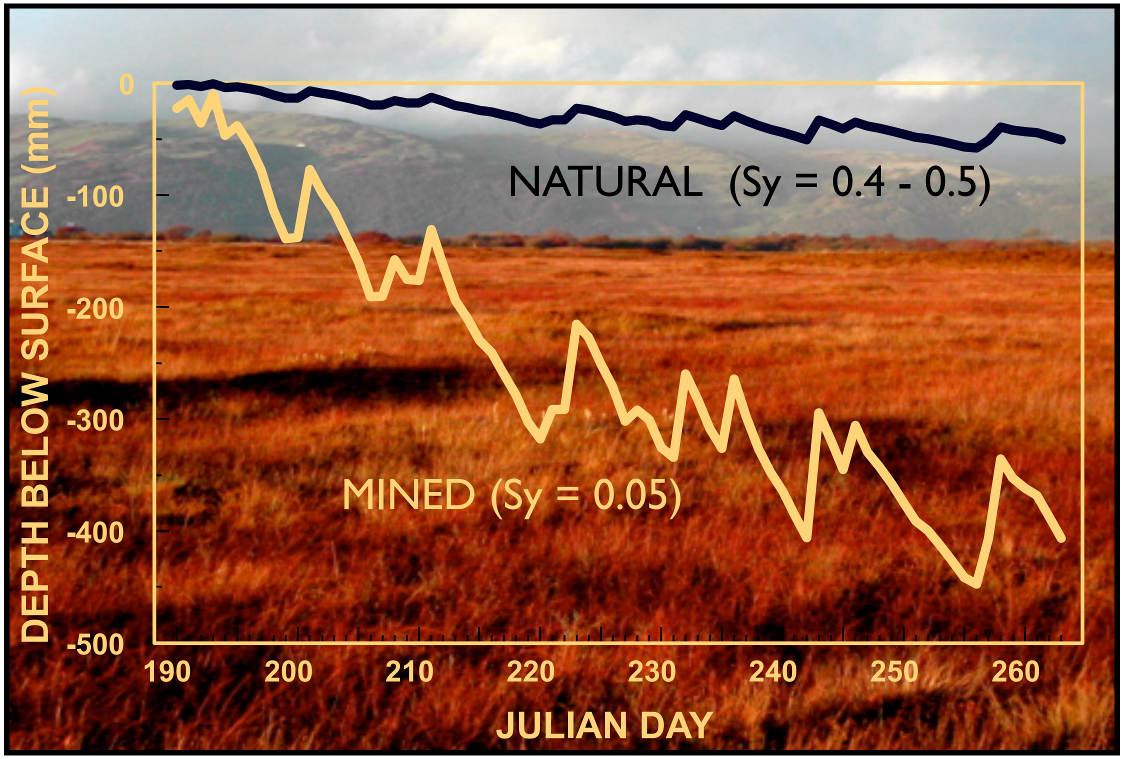
UNITS: g C m^{-2} yr^{-1}



Petrone et al. 2003 (Wetland Ecol. Mgmt.)

Peatlands and Regime Shifts

Moss removal allows positive feedback dominance



Sphagnum moss increases specific yield (S_y)

High and stable water table (WT)

Low soil water tension

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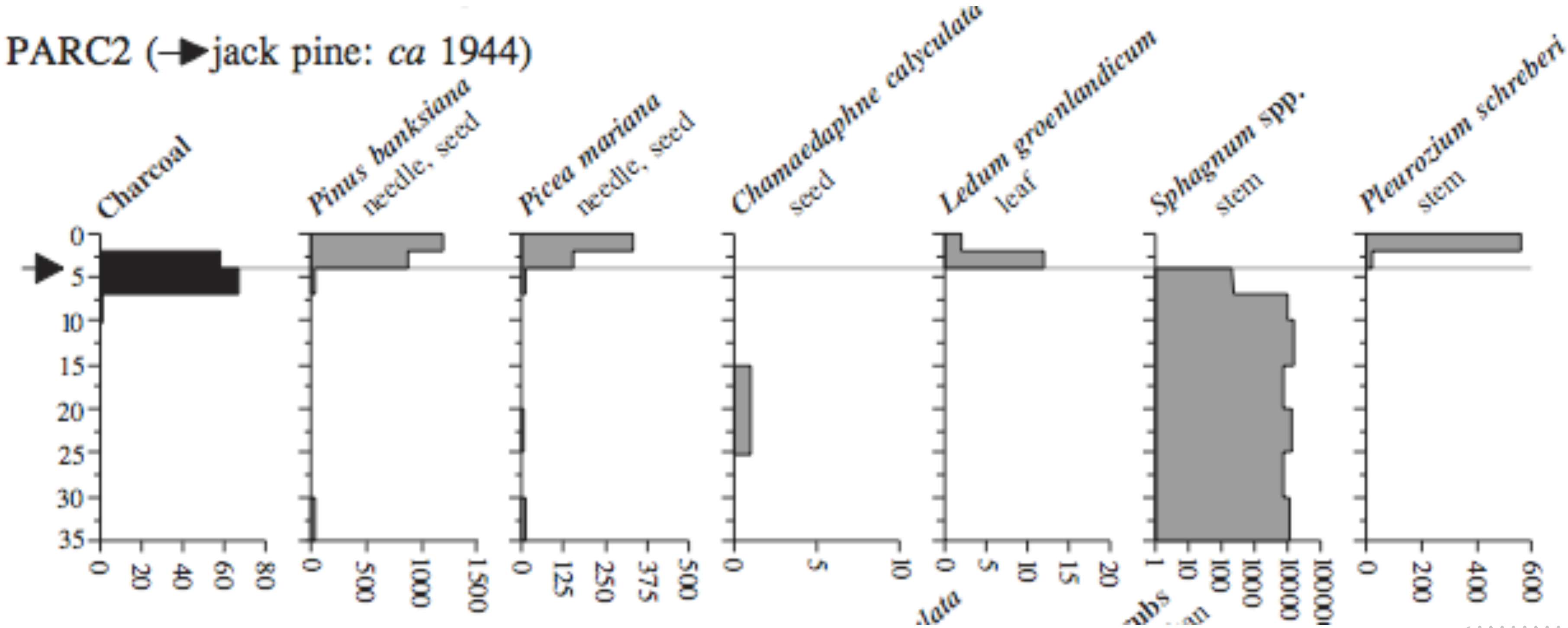
Source: Hilbert et al., (2000) Journal of Ecology

Peatlands and Regime Shifts

Post-drainage and wildfire regime shift



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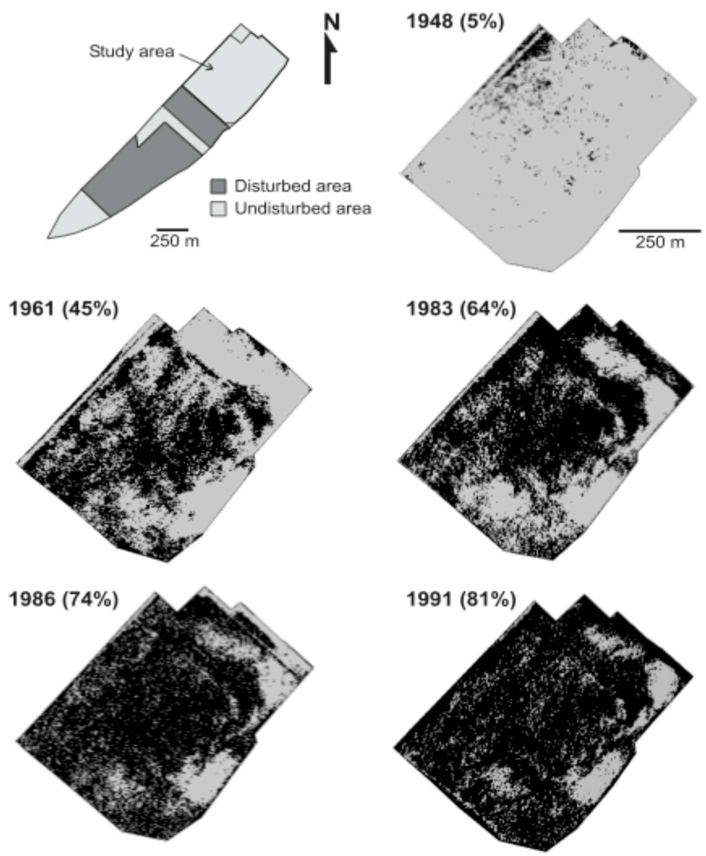
Source: Pellerin and Lavoie (2003) Journal of Ecology

Peatlands and Regime Shifts

Drying, wildfire and afforestation



Decrease water table

Increase peat density

Increase tree growth and cover

Increase evapotranspiration

Increase rainfall interception

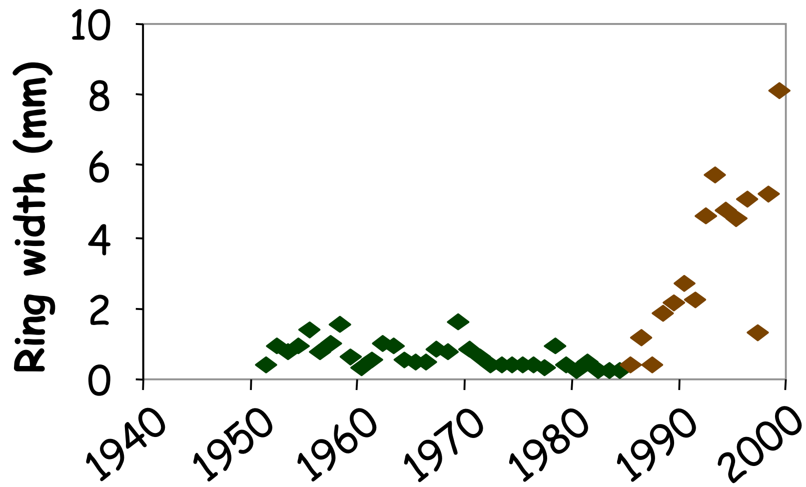
Increase fuel for wildfire

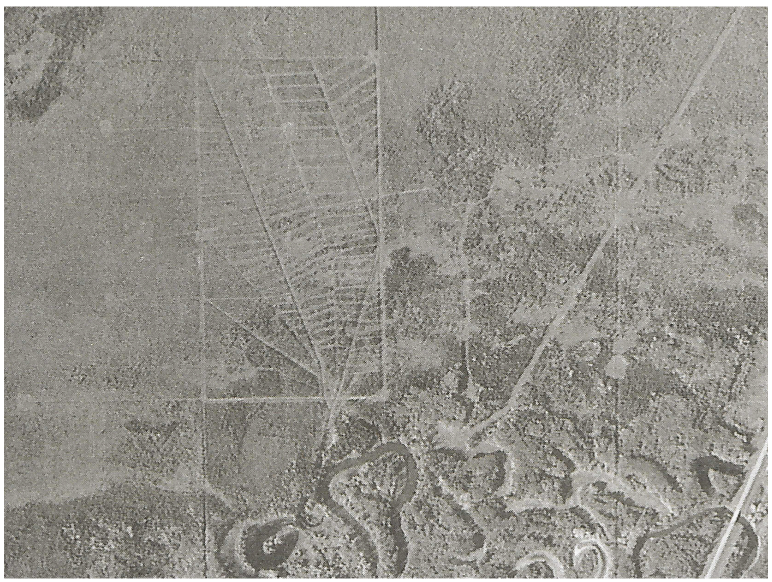
Decrease Sphagnum moss

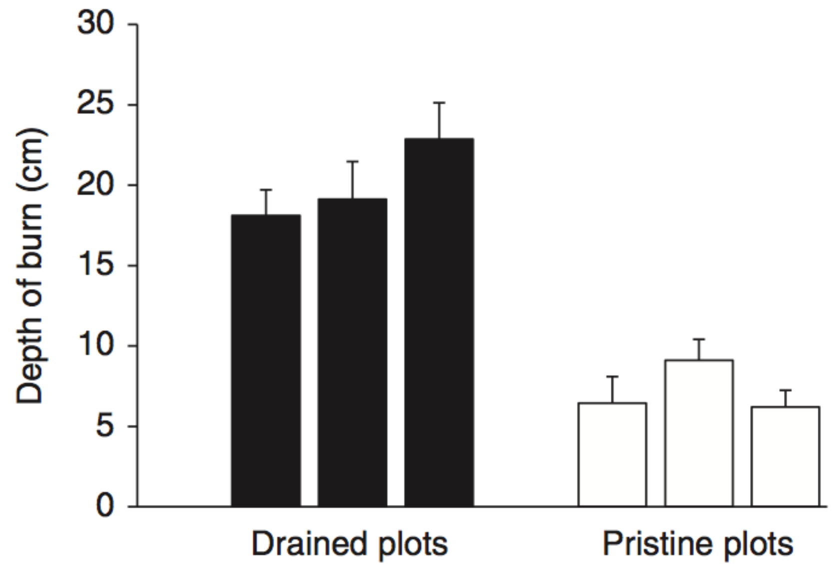
Decrease moisture content

Increase burn severity

Source: Waddington et al (2014) Ecohydrology; Pellerin and Lavoie (2003) Ecoscience







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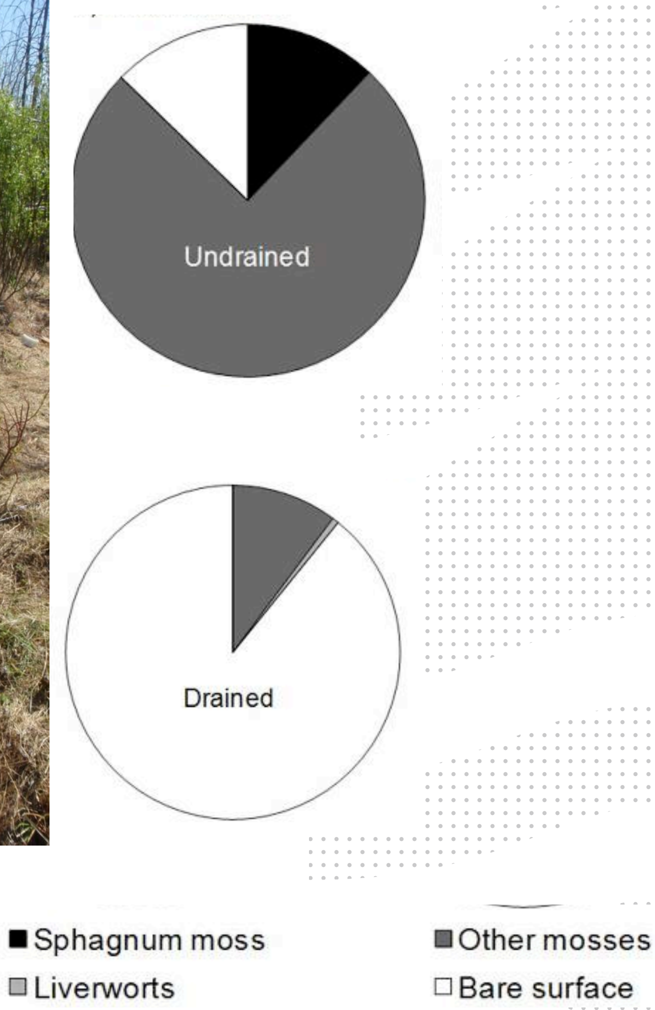
Source: Turetsky et al. (2011) Nature Communications

Peatlands and Regime Shifts

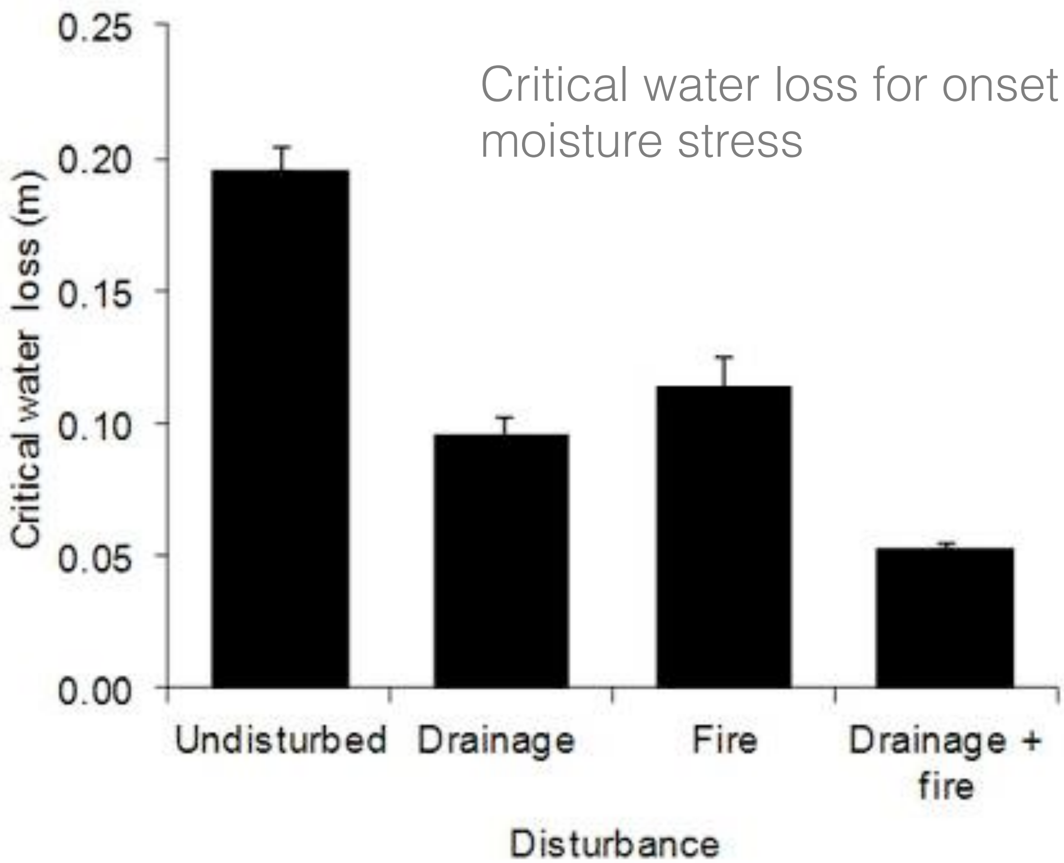
Compound disturbance leads to an ecosystem regime shift



Peatlands and Regime Shifts

Drying, wildfire and afforestation

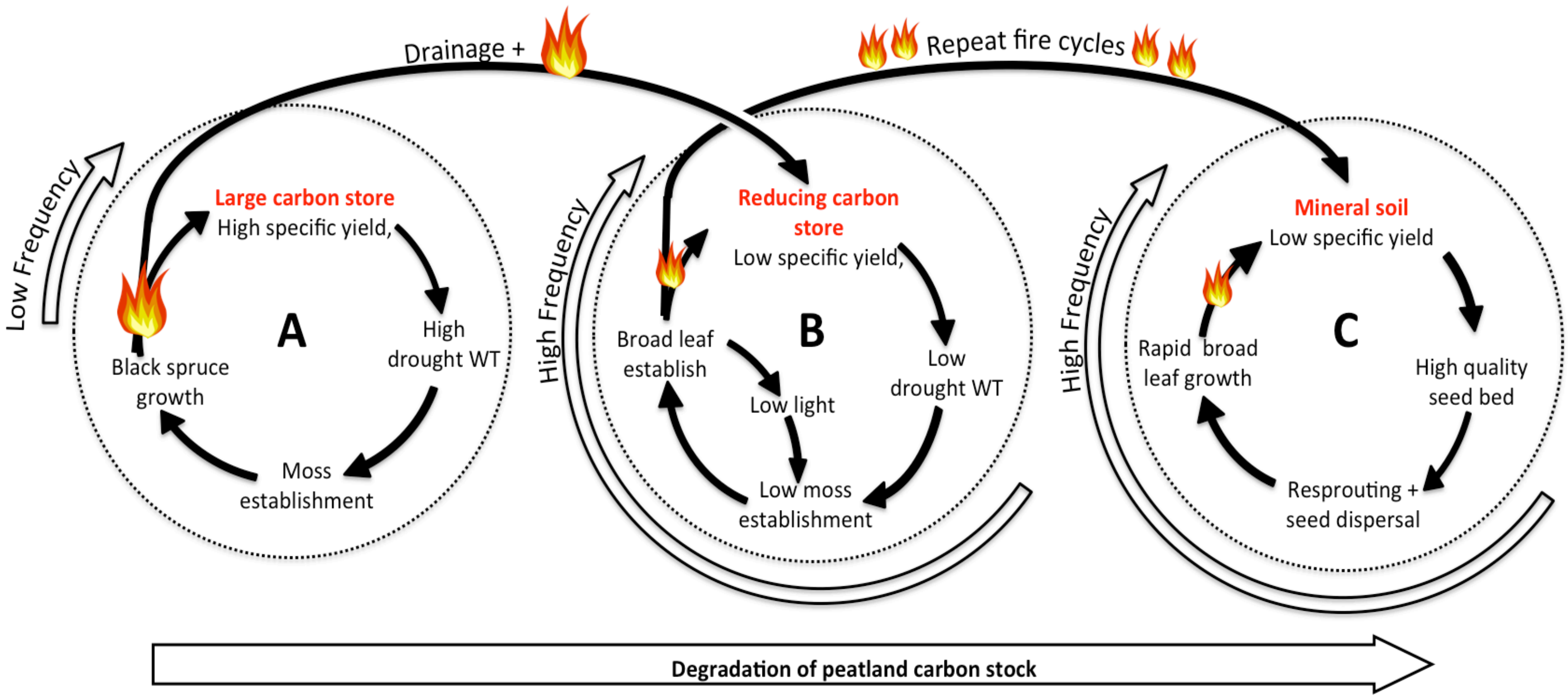
Critical water loss for onset of Sphagnum moisture stress



■ Sphagnum moss ■ Other mosses
□ Liverworts □ Bare surface

Peatlands and Regime Shifts

Regime shift increases vulnerability to future wildfire and degrades carbon stock



Russia 2010

1000 peat fires (drained, mined)
200,000 ha burned
Extreme smoke pollution
>$10B in damage

2010 Russian Peat Fires (Russia)

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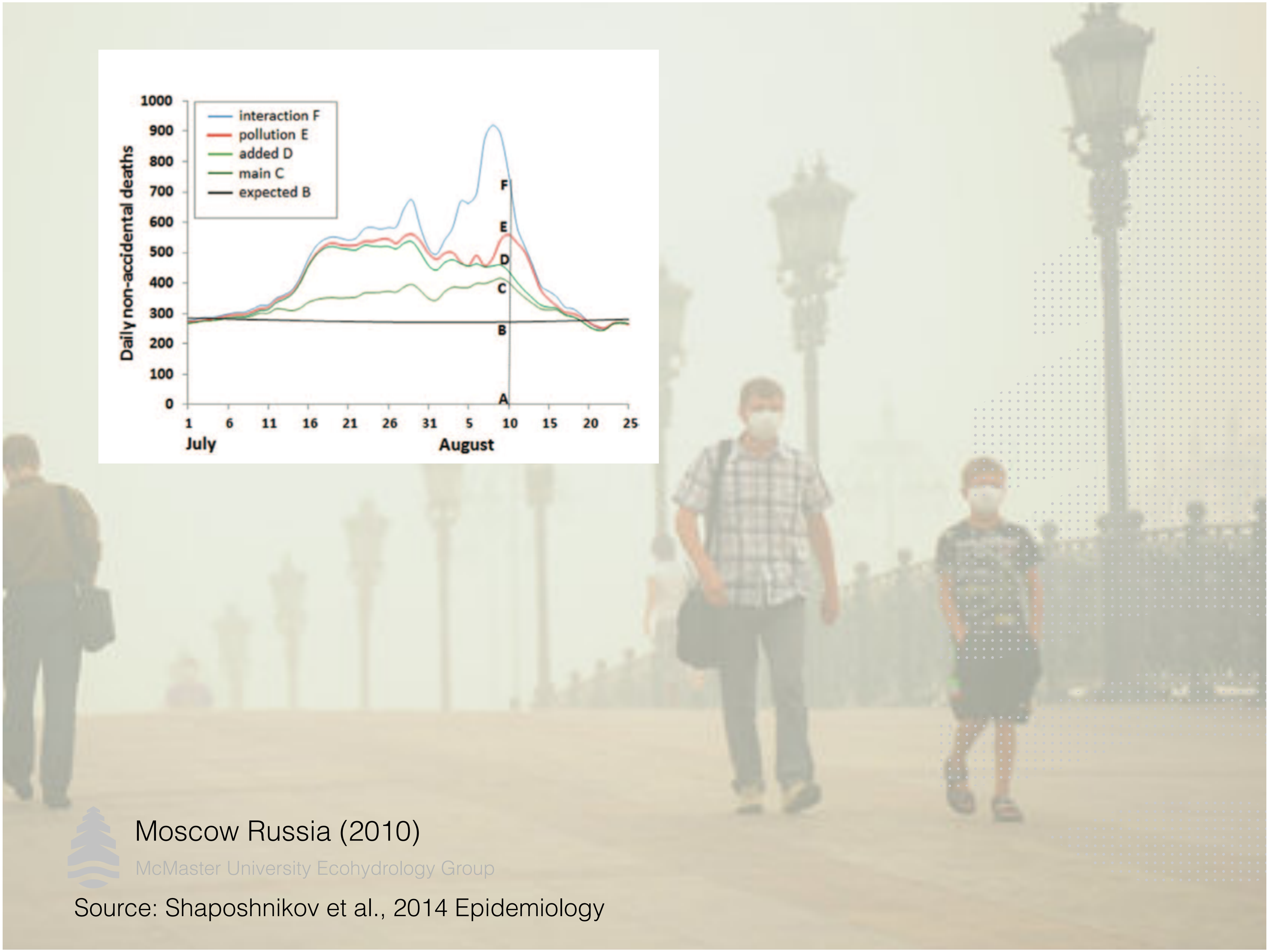
Source: James Hill, The New York Times (http://www.nytimes.com/imagepages/2010/08/13/world/RUSSIA1.html)



Moscow Russia (2010)

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Source: Shaposhnikov et al., 2014 Epidemiology

Ecohydrology By Thinking Outside The Bog

Shifting paradigms in an era of shifting peatland ecosystems

Mike Waddington @MACecohydrology · 6m
1/4... #BHS2014 Penman Lecture. Acrotelm-catotelm model unsuitable for addressing peatlands as complex adaptive systems

Mike Waddington @MACecohydrology · 5m
2/4.. #BHS 2014 Penman Lecture. New peatland research approach: Quantifying ecohydrological thresholds in an ecological resilience framework

Mike Waddington @MACecohydrology · 4m
3/4... #BHS2014 Peatlands are generally resilient to disturbance but compound disturbance of drainage and wildfire may invoke regime shift

Mike Waddington @MACecohydrology · 2m
4/4... #BHS2014 Penman Lecture. Restoration of drained and/or mined peatlands needed to mitigate potential wildfire vulnerability

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